USING THE SPY-1/TEP TO NOWCAST OCEANIC THUNDERSTORMS FOR NAVAL OPERATIONS

by

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1.0 Introduction

At approximately 2300 UTC on 15 May 2000, naval flight operations on the aircraft carrier USS GEORGE WASHINGTON (CVN 73) were suspended in mid-cycle due to severe weather events that included a waterspout, intense lightning and an apparent microburst. The GEORGE WASHINGTON was participating in a simulated wartime exercise off the coast of North Carolina during a Joint Task Force Exercise (JTFEX). As part of the JTFEX, the U.S. Navy and the Lockheed Martin Corporation were testing a weather radar processor called the Tactical Environmental Processor (TEP) that computes radar moment data (reflectivity, radial velocity and spectrum width) from the four-face, agile beam AN/SPY-1 radar (McNellis, 2003). The SPY-1/TEP system was deployed on the USS NORMANDY (CG 60) and collected considerable data on this severe weather event.

As part of the TEP demonstration, various personnel, including the second author, were onboard three of the Battle Group ships to observe the TEP system and to assess its usefulness during the JTFEX. With the TEP processor on the NORMANDY, images of the composite reflectivity were sent approximately every 30 minutes to the USS MT. WHITNEY and the GEORGE WASHINGTON through use of the Naval Atlantic Meteorological and Oceanographic Command (NLMOC) Secret Internet Protocol Router Network (SIPRNET).

The SPY-1/TEP data are shown to be an excellent tool for naval strategic and operational planning purposes when inclement weather conditions exist. Strategies for the best utilization of these data during naval operations are proposed. Further, the ability to nowcast convective conditions is shown and could have significant value to the naval warfighter.

The National Center for Atmospheric Research (NCAR) Auto-Nowcast System (ANC) provides short-term (0-60 minute), time- and space-specific nowcasts of thunderstorm intensity using fuzzy-logic, data fusion techniques (Mueller et al, 2003). The ANC has been successfully deployed at multiple, land-based sites to produce automated nowcasts in operational environments. These sites include the Army Test and Evaluation Command at the White Sands Missile Range in New Mexico and the Redstone Arsenal in Alabama.

The ANC uses a variety of input data such as Doppler radars (like the SPY-1/TEP), GOES satellite imagery, numerical model output and upper air data, among others. The ANC has had considerable development and testing on continental convection. The ANC has been successfully tested on its ability to nowcast oceanic convection (Kessinger et al, 2001) using data collected with the SPY-1/TEP during its first deployment on the USS O'KANE in 1999.

2.0 15 May 2000 Data Collection

The SPY-1/TEP collected data from 1945 UTC on May 15th to 0437 UTC on May 16th. Radar volumes were spaced at uneven intervals during this time with a total of 40 volumes collected. Each volume consists of 11 elevation angles that span from the horizon to about 19^{o} in elevation and 360^{o} in azimuth (i.e., a surveillance scan). Unfortunately, due to technical difficulties, the SPY-1/TEP was able to collect data only on the reflectivity channel for this case. Therefore, the radial velocity and spectrum width fields were not available.

The GOES-8 satellite collected visible and infrared imagery at about 15 minute intervals. Numerical model runs of the Rapid Update Cycle (RUC) provide the steering level flow and the near-surface flow fields used to advect features and to estimate vertical shear of the horizontal winds.

3.0 The 15 May 2000 Storm

The second author was onboard the aircraft carrier GEORGE WASHINGTON and had direct observations of the storm and its effect on carrier aircraft operations. He observed a line of cumulus congestus clouds that formed into cumulonimbus clouds. Subsequently, a waterspout formed about 7nmi off the starboard beam of the carrier at 2250 UTC and lasted about 6 min. Next, an apparent microburst[1] containing heavy rain formed directly over the ship. Intense lightning activity was present in all quadrants. The carrier was sailing northward at the start of the event into strong headwinds (into the initial storm outflow directly ahead of the ship) with aircraft being launched into the face of the storm. Aircraft operations continued until conditions deteriorated to aircraft minimums. The winds then shifted to strong southerly, indicating tailwind flow on the backside of the microburst. With southerly winds, the flight deck was not suitable for aircraft operations. Operations were not restarted until the carrier was sufficiently north of the storm region to allow the ambient northerly flow to return. Most importantly, an FA-18 tactical fighter/bomber jet was launched in a northerly direction at the instant of the apparent microburst transect, a serious situation that

[1] The classification of this event as an "apparent" microburst is because TEP was only collecting reflectivity data and not radial velocity data. Therefore, Doppler wind data were not available to verify the point observations that a microburst seemed to occur.

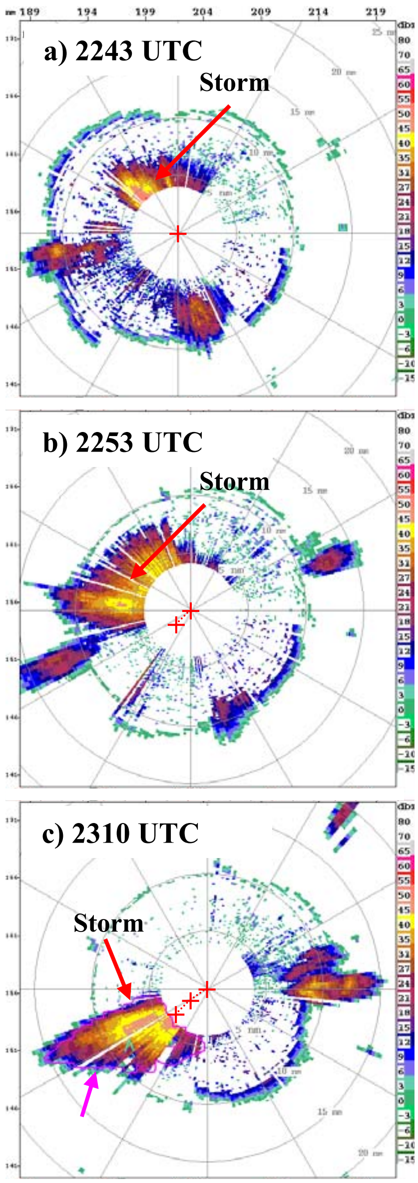


Figure 1. SPY-1/TEP reflectivity (dBZ) is shown at 7° elevation at a) 2243, b) 2253 and c) 2310 UTC. The movement of the USS NORMANDY position is indicated by the red cross-hairs. Red arrows point to the microburst storm. In c), the storm-tracking algorithm has identified the storm (magenta contour). Range rings are at 5 nm intervals.

could have been avoided if a true microburst detection capability were available via TEP. Fortunately, the aircraft was able to make a successful recovery.

Figure 1 shows the TEP radar reflectivity of the microburst-producing storm at three times (2243, 2253 and 2310 UTC) that cover a 27 minute period. The 7° elevation angle is shown due to its close proximity to the radar. At this range, the radar is sampling the microburst storm at 3-6 kft (or 1-2 km) mean sea level (msl). The NORMANDY is located at the center of the radar display. The GEORGE WASHINGTON was located well within 10 nmi to the NW of the NORMANDY (G. Young, personal notes). Reflectivity data are not available at short ranges because the range to the first range bin processed by TEP is at 4.26 nmi.

At 2243 UTC, the microburst storm is NW of the NORMANDY with a maximum reflectivity of 55 dBZ. Ten minutes later, at 2253, the NORMANDY has moved northeastward away from the storm and its maximum reflectivity has decreased to 45 dBZ. At the last time of 2310, the storm has maintained its intensity and the storm detection algorithm has defined the storm for the first time, as indicated by the magenta contour. The storm detection algorithm requires a storm be defined for a user-specified time interval to limit false detections. This storm continued to evolve and effect operations for nearly an hour. Additional time periods will be shown at the conference.

These figures dramatically show the advantage of onboard weather radars to provide real-time information into the decision-making procedures used for aircraft operations. Similar to land-based radars used at airports (such as the Terminal Doppler Weather Radar or TDWR), the TEP can provide much needed information about the weather conditions around carriers during aircraft operations. Automated detection algorithms for detecting hazardous wind shear such as microbursts have been deployed on the TDWR and could be adapted for use on the TEP. This information will improve personnel safety and will enhance aircraft operations and efficiency.

In addition to the use of TEP in diagnosing current weather conditions as shown with this case, the TEP can be used to assist in producing 0-60 minute nowcasts of storm initiation, development and dissipation. To illustrate this, the NCAR Auto-Nowcast System (ANC) is initialized with TEP data and other data sets to produce a 20 minute nowcast for two storms that occurred about 2 hours prior to the microburst storm.

In addition, the ANC can readily become part of the NOWCAST for the Next Generation Navy, as reported by Strahl et al. (2003) in this conference. In NOWCAST, the ANC detection, tracking, and nowcast prediction can be combined with various other through-the-sensor and derived products such as ceiling, visibility, and flight category nowcasts, satellite and merged satellite and radar depictions, and very importantly, three-dimensional wind fields derived from data assimilation of weather radar reflectivity and velocity, satellite visual and IR data, and mesoscale model output.

4.0 The Auto-Nowcast System

The ANC is a fuzzy logic, data fusion system that mimics the nowcasting decisions made by humans by combining a variety of data sets and by applying conceptual models that explain how a storm will initiate, grow and dissipate. See Mueller et al. (2003) for a complete description of the ANC. Input data sets for the ANC include the TEP base data, GOES-8 imagery, RUC wind fields and the human-inserted boundary positions, described below. A 20 minute nowcast of two convective cells is produced.

For this post-mission analysis, SPY-1/TEP reflectivity data are thresholded at 3 dBZ, removing most of the radar-detected boundary layer convergence zones. Boundary layer convergence zones provide much of the necessary uplift to initiate and sustain convective development. For nowcasting surface-based convection, knowing the location of these boundaries is a critical element. Therefore, the locations of boundary layer convergence zones are inserted by hand at several times to allow for extrapolation by the RUC winds. A time period was selected such that the TEP radar scans were evenly spaced and with enough daylight that the position of the boundary layer convergent zone could be estimated from the GOES visible imagery. The initial time is 2109 UTC and the nowcast time is 2129 UTC.

The ANC defines these regions of uplift using the boundary layer convergence zone and associated vertical shear of the horizontal winds as determined from the RUC model. The RUC winds at 6 kft (or 2 km) are shown in Figure 2. Figure 3 illustrates the process of boundary position insertions, their extrapolation and the definition of the "boundary zone". Once the boundary convergence zone locations are inserted, the RUC winds extrapolate the position to the nowcast time and a "boundary zone" is defined that is based on the extrapolation speed. Convection initiation and development is supported within the boundary zone. The boundary zone is an input into the ANC.

The ANC extrapolates existing radar-detected storms using the steering winds determined from the RUC model. Figure 4 shows the storm detections and their extrapolation to the nowcast time. The extrapolated storm positions are input into the ANC. Interactions between storms and the boundary zone regulate storm evolution. When a storm is close to or within a boundary zone, their updrafts remain vigorous and the storm is

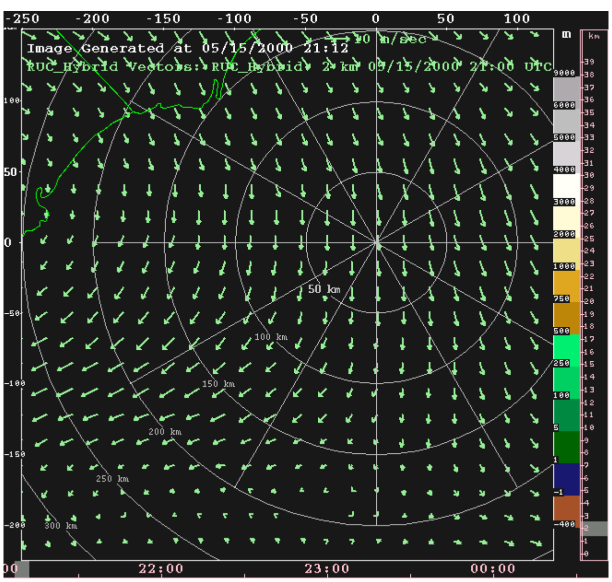


Figure 2. The RUC wind field at 6 kft (or 2 km) for 2100 UTC.

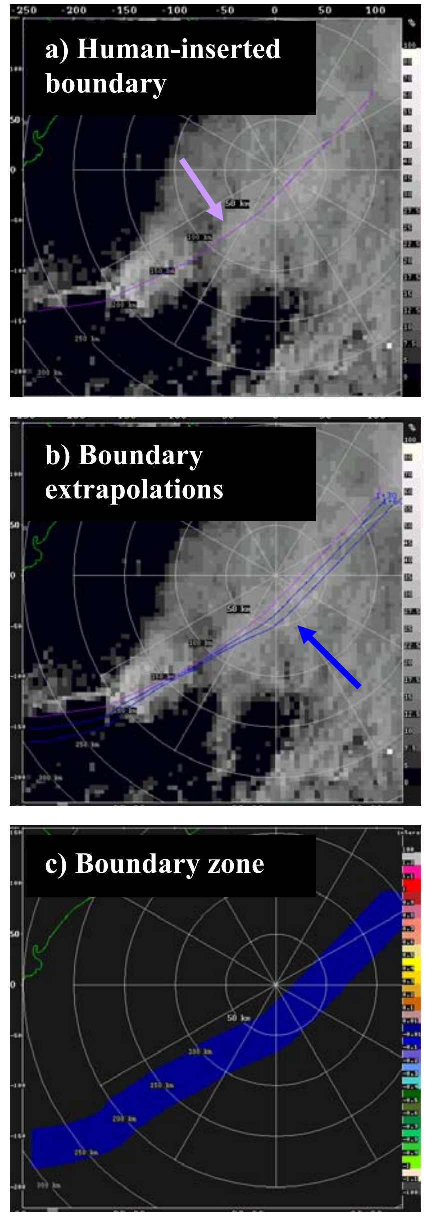


Figure 3. The location of a human-inserted boundary layer convergence zone is estimated from visible satellite imagery in a). The RUC winds are used to extrapolate the boundary positions in b). The "boundary zone" is shown in c).

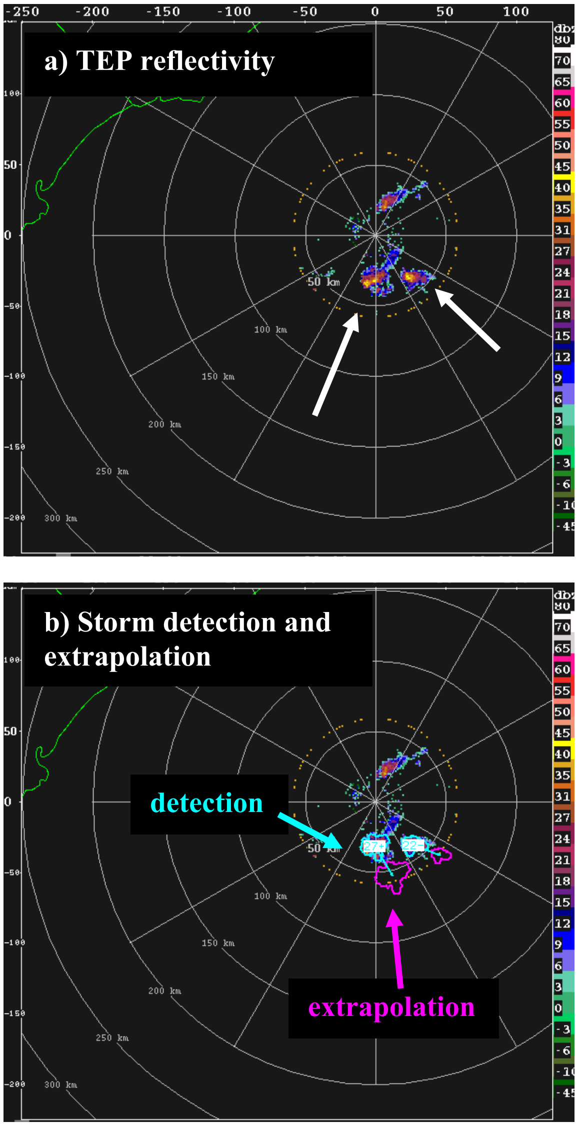


Figure 4. TEP reflectivity (dBZ) is shown for 2109 UTC at 2 km. The two storms of interest are indicated in a) by arrows. In b), the storm tracking algorithm has identified the two storms (cyan contours) and has extrapolated their position to 20 minutes in the future (magenta contours).

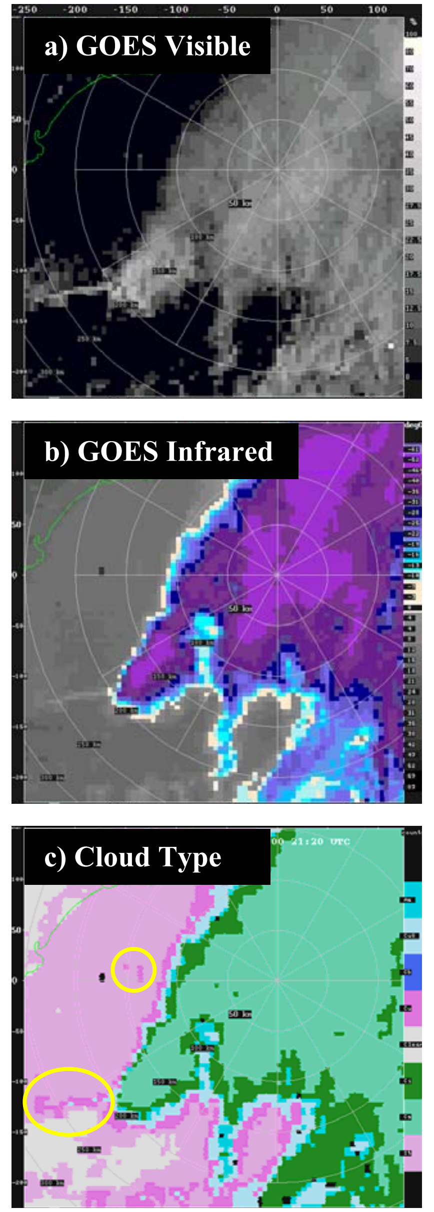


Figure 5. GOES imagery is shown for the a) visible channel and b) infrared channel. Cloud type as determined from a) and b) is shown in c). The yellow circles enclose regions of cumulus that have the potential to develop into storms.

expected to persist. As a storm advects away from the boundary zone, the updraft typically weakens and the storm dissipates.

GOES imagery data are used as a proxy for detailed stability information (see Figure 5). A cloud classification scheme that uses lookup tables to define cloud type estimates the presence of cumulus or cumulus congestus clouds. These cloud types suggest that atmospheric conditions exist that are supportive of vigorous, deep convection. These cloud types are advected to their position at the nowcast time using the RUC winds.

5.0 ANC Results

The likelihood fields from each category (boundary zone, RUC winds, storm extrapolations and cloud types) are put into the

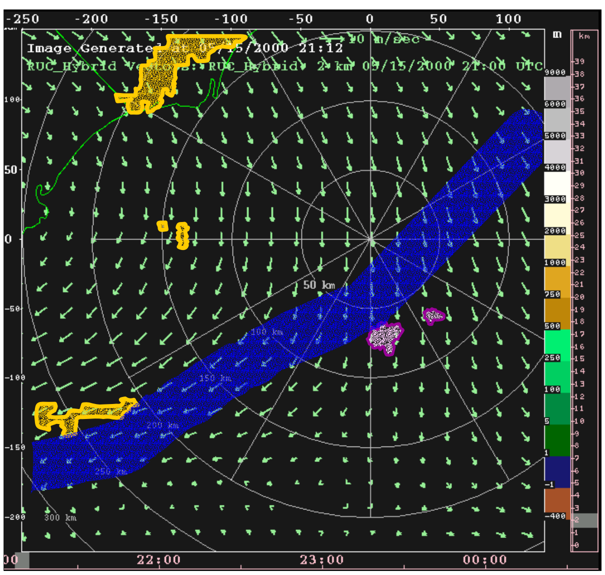


Figure 6. An illustration showing how the various likelihood fields are combined in the data fusion process of the ANC.

ANC as shown in Figure 6. Regions of overlap indicate regions likely for convection to continue.

The ANC produces a good 20 minute nowcast of the two storms. Figure 7 shows the 20 minute nowcast along with the verification data. Specific verification highlights are:

a) The nowcast polygons (purple shapes) for the two storms are slightly southeast of the verification positions but within acceptable limits. Further, the eastward expansion of the western nowcast polygon covers the position of the new cell.

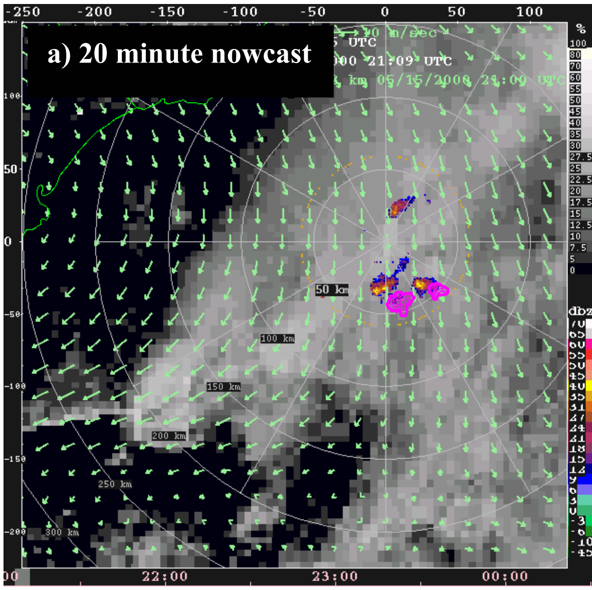
b) The cumulus clouds in the western part of the domain that are near the boundary zone are correctly nowcast to not intensify into deep convection because they do not have sufficient low-level forcing.

c) The convective cell that was north of the SPY-1/TEP was correctly nowcast to dissipate because it is outside of the boundary zone.

These results show that nowcasting can give advance notice of storm location and intensity. This advance notice can provide important strategic and operational information that will be useful for planning and conducting aircraft and naval operations.

6.0 Strategic and Operational Issues for the SPY-1/TEP

As stated earlier, the output from the Auto-Nowcast System, especially when combined with a more extensive NOWCAST system being developed by NRL, provides the ability for a carrier Battlegroup Rapid Environmental



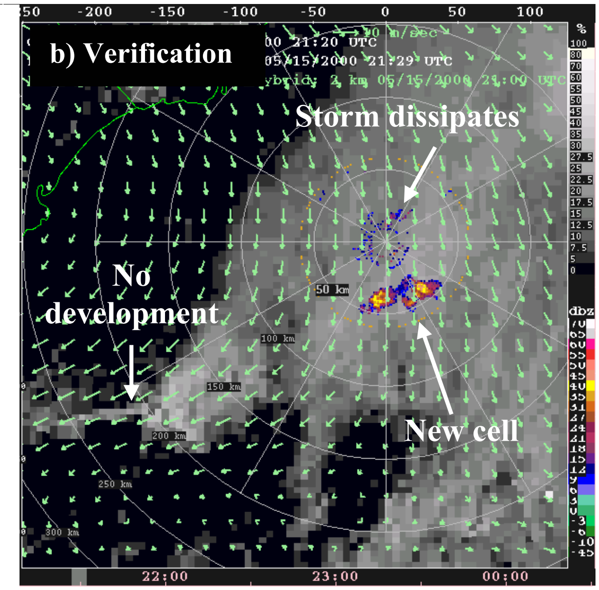
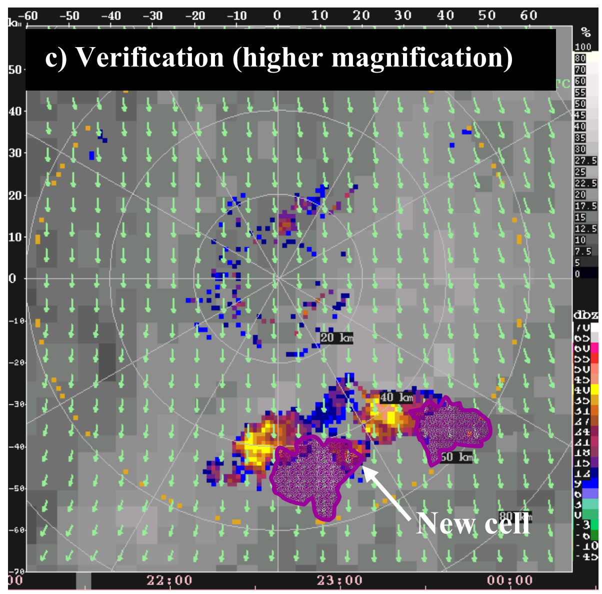


Figure 7.Output from the ANC is shown. In a), the nowcasted locations of storm positions are shown by purple shapes with the current TEP reflectivity (dBZ). In b), the TEP reflectivity is shown at the verification time. Notice that the cell to the north of the two main cells dissipates, a new cell forms in between the two cells and that no convective development occurs in the region of cumulus clouds to the far west of the two cells. In c), the two storms are shown at higher magnification with the 20 minute nowcasts of storm position shown by the purple shapes.



Assessment. This in turn provides the weather component of a DOD-wide concept of the 4-Dimensional Cube, a spatial and temporal depiction of the battle environment, focusing on the very high resolution for two hours before and up to two hours after a carrier strike operation.

Ultimately, the objective is to ensure improved mission effectiveness (e.g., bombs on target), and to improve mission safety (e.g., safe departure and return to the carrier, avoiding hazardous weather). The latter example also addresses mission effectiveness by providing for strategic planning in an autonowcasting sense, to smoothly plan sorties that take rapidly changing weather conditions into consideration. Similar objectives can be focused on amphibious, special (covert) operations, and a large array of intelligence missions.

Recently the Commanding Officer of the Second Fleet has listed 10 top objectives for the Navy Meteorology and Oceanography (METOC) community for fiscal year 2004. Three of them include the following (paraphrased):

- Add an additional weather (METOC) officer on each carrier and on large-deck amphibious ship, to allow a more succinct addressing of weather integration into mission planning.

- Develop "show-stopper" demonstrations of weather capabilities that provide a high degree of capability to the modern Navy in transition to a 3 and 4 dimensional Battlespace environment; these show-stoppers are to integrate activities with the carrier air wing and amphibious air squadron.[2]

- Develop weather radar capability at sea, using existing AN/SPY-1 and AN/SPS-48 radar weather radar at sea, and make weather radar presentations available to other unit. Emphasis would be on detection, tracking, and predicting hazardous weather for ships and aircraft

[2] We believe that ANC and NOWCAST certainly fit such a request.

7.0 Summary

The Tactical Environmental Processor (TEP) was demonstrated during the JTFEX of May 2000. The TEP provided radar moment data to onboard users. Once operationally deployed in the Navy's fleets, the TEP will prove itself invaluable to aircraft and naval operations, as suggested by the examples shown in this paper. The TEP will have uses for diagnosing current weather conditions as well as nowcasting weather conditions in the near-future. Finally, the capability described here fits the objectives of a more effective weather role in the changing warfighter need in the modern military at sea.

8.0 Acknowledgements

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